STRUCTURE OF THE FINAL STATES IN HIGGS PRODUCTION AT HADRONIC COLLIDERS

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We quantify the rate and the signal-to-background ratio for Higgs $\to b\bar{b}$ detection in double-diffractive events at the Tevatron and the LHC. The signal is predicted to be very small at the Tevatron, but observable at the LHC. We exemplify the diagnostic power of hadronic antenna pattern by considering the topology of hadronic flow corresponding to Higgs $\to b\bar{b}$ events.

One of the biggest challenges facing the high-energy experiments is to find a good signal with which to identify the Higgs boson. Following the closure of LEP2, the focus of searches for the Higgs is concentrated on the measurements at the present and forthcoming hadron colliders, the Tevatron and the LHC.

To ascertain whether a Higgs signal can be seen, it is crucial to show first that the background does not overwhelm the signal. For instance, as well known, an observation of the inclusive intermediate mass Higgs production, that is pp or $p\bar{p} \to HX$ with $H \to b\bar{b}$ is considered to be impossible because of an extremely small signal-to-background ratio due to gluon-gluon fusion, $gg \to b\bar{b}$. One possibility is to observe the Higgs in association with massive particles (W/Z, t-quarks). Here we discuss two (less conventional) approaches to tackle the background problem in the case of central $H \to b\bar{b}$ production.

One way to reduce QCD background, is to study the central production of the Higgs in events with a large rapidity gap on either side, see [1] and references therein. An obvious advantage of the rapidity gap approach is the spectacularly clean experimental signatures: hadron-free ('no-flight') zones between the remnants of the incoming protons and the produced system.

Another possibility is to use the topology of hadronic flows corresponding to Higgs production to dissect the colour structure of the final state [2]. Topologometry of hadronic flows (event portrait) proves to be a very successful discriminative tool to probe the detailed properties of multi-jet events in various hard processes, see [3] and references therein.

We begin with double-diffractive processes of the type

$$pp \;\to\; p \,+\, M \,+\, p, \qquad (1)$$

where the protons remain intact. They allow the reconstruction of the "missing" mass M (say a Higgs boson) with good resolution, and so provide an ideal way to search for new resonances and threshold behaviour phenomena [4]. Moreover, in exclusive processes with forward protons the incoming gg state satisfies special selection rules, namely it has $J_z = 0$, and positive C and P parity. These selection rules are of crucial importance in suppressing the QCD background when searching for the $H \to b\bar{b}$ signal.

In order to use the 'missing-mass' method to search for a Higgs boson, via the $H \to b\bar{b}$ decay mode, we have to estimate the QCD background which arises from the production of a pair of jets with invariant mass about M_H. The good news is that the signal-to-background ratio does not depend on the uncertainty in the soft rescattering effects, and is given just by the ratio of the corresponding $gg \to H \to b\bar{b}$ and $gg \to b\bar{b}$ subprocesses.

A remarkable advantage of the signature (1) for the $H \to b\bar{b}$ events is that here the $H \to b\bar{b}$ signal/$b\bar{b}$ background ratio is strongly enhanced due to colour factors, gluon polarization selection and the spin $\frac{1}{2}$ nature of quarks. An explicit calculation assuming $M_H = 120$ GeV and imposing the $\theta > 60^\circ$ cut of low E_T jets, gives a signal-to-background ratio

$$\frac{S}{B_{b\bar{b}}} \gtrsim 4 \left(\frac{1 \text{ GeV}}{\Delta M} \right). \tag{2}$$

The signal is, thus, in excess of background even at mass resolution $\Delta M \sim 2$ GeV, so the $b\bar{b}$ background should not be a problem. Unfortunately the situation worsens for inclusive Higgs production, where the polarization arguments become redundant. In this case $S/B_{b\bar{b}}$ ratio is additionally suppressed by a factor $\sim 20 - 30$.

While the predictions for the $S/B_{b\bar{b}}$-ratio look quite favourable for Higgs searches using the missing-mass method, the expected event rate casts a shadow on the feasibility of this approach (at least for experiments at the Tevatron). In our recent analysis we found

$$\sigma_H = \sigma(p\bar{p} \to p + H + \bar{p}) \simeq 0.06 \text{ fb} \quad \text{at} \quad \sqrt{s} = 2 \text{ TeV}, \tag{3}$$
$$\sigma_H = \sigma(pp \to p + H + p) \simeq 2.2 \text{ fb} \quad \text{at} \quad \sqrt{s} = 14 \text{ TeV} \tag{4}$$

for a Higgs boson of mass 120 GeV. These values correspond to the cross section ratio

$$\sigma_H / \sigma_{\text{incl}\,(gg \to H)} \simeq 10^{-4} \tag{5}$$

and are much lower than the predictions to other authors. However the recent CDF study of diffractive dijet production [5] provides strong experimental evidence in favour of our pessimistic estimates.

We emphasize that low expected signal cross section at the Tevatron just illustrates the high price to be paid for improving the $S/B_{b\bar{b}}$ ratio by selecting events where the protons remain intact. Nevertheless, there is a real chance to observe double-diffractive Higgs production at the LHC, since both the cross section and the luminosity are much larger than at the Tevatron. For an integrated luminosity of 100 fb^{-1} at the LHC we expect, for $M_H = 120$ GeV, about 200 $H \to b\bar{b}$ events.

Let us now turn to hadronic radiation pattern for $H \to b\bar{b}$ production at hadronic colliders. This can be used as a discriminative tool to distinguish between the signal and the conventional QCD background. In [2] the radiation samples were compared for the signal ($gg \to H \to b\bar{b} + g$) and background ($gg \to b\bar{b} + g$) production. It was found that the main difference between these two came from the radiation *between* the final-state jets. In particular, there is approximately 4/3 more radiation between the final-state jets for the Higgs production. This is due to the absence of a colour connection between the quarks in the background process.

The radiation patterns were studied also for Higgs production in association with a W boson in the process

$$q\bar{q}' \;\to\; W^* \;\to\; W(\to \ell\nu_\ell)\, H(\to b\bar{b}) \tag{6}$$

and for the background process

$$q\bar{q}' \;\to\; W(\to \ell\nu_\ell) \;+\; b\bar{b}, \tag{7}$$

when $M_{b\bar{b}} \sim M_H$. Again the signal and background processes are shown to have quite different radiation patterns.

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